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GEOGRAPHIC DISTRIBUTIONS OF SPECIES PROPORTIONS FOR DOLPHINS OF THE EASTERN TROPICAL PACIFIC

by

Jay Barlow and Rennie S. Holt

ADMINISTRATIVE REPORT LJ-84-27

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GEOGRAPHIC DISTRIBUTIONS OF SPECIES PROPORTIONS FOR DOLPHINS OF THE EASTERN TROPICAL PACIFIC

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ABSTRACT

Overall proportions of the various dolphin species involved in the eastern Pacific tuna fishery are calculated from sightings made from fishing and research vessels. Considerable geographic variability is found in dolphin proportions. Overall species proportions are therefore calculated from a weighted sum of the species proportions within 5-degree geographic strata. Variances in the estimates of these proportions are calculated using bootstrap methods.

The effects of various sighting factors are tested using bootstrap statistics. Estimates of species proportions from data collected on tuna vessels are found to be significantly different from estimates based on research vessel data. Support is given for the superiority of research vessel estimates over those made from tuna vessel sightings. Other factors tested include sighting distance, sighting cue, school size, year, sea state, season, search effort, sighting platform, and distance from previous sighting.

Nearest neighbor analyses show considerable geographic heterogeneity in species compositions, even within 5-degree squares. Schools of like species are clustered together. These results emphasize the importance of random or systematic search patterns in surveys of dolphin species proportions.

INTRODUCTION

The relative proportion of various dolphin species in the eastern tropical Pacific (ETP) has played an important role in the estimation of dolphin population sizes. In current estimation procedures, species proportions from tuna and reseach vessel sightings are used to prorate total dolphin density estimates (derived from aircraft line-transects) to obtain individual species density estimates (Holt and Powers, 1982). These estimates of species proportions have not incorporated information on the fine scale geographic distribution of individual species. In this paper we examine some factors which affect the estimates of overall species proportions from tuna and research vessel sightings, particularly the effect of the geographic distribution of species.

Our studies of dolphin abundance (and therefore species proportions) are designed to assess the effect of the tuna fishery on dolphin populations in the ETP. Three species, the spotted dolphin (Stenella attenuata), the spinner dolphin (S. longirostris), and the common

dolphin (Delphinus delphis), were considered because they are the predominant species which have been subject to incidental mortality as a result of tuna purse seining (Smith, 1979). In addition, the striped dolphin (S. coeruleoalba) and the Fraser's dolphin (Lagenodelphis hosei) were included because these two species are difficult to distinguish from the other three during aerial transects and thus are included in total dolphin density estimates. Also, several of the five species often swim together to form multi-species aggregations. Proration of dolphin abundance from aerial survey density thus requires the inclusion of all five species. Estimated geographic distributions for the stocks of the four most abundant species are given by Perrin, Scott, Walker, Ralston and Au (1983).

MATERIALS

Data for this report were gathered by technicians and scientists aboard United States registered tuna purse-seiners and National Oceanographic and Atmospheric Administration (NOAA) research vessels. All observers were trained and employed by the National Marine Fisheries Service (NMFS).

Research Vessels

Research cruises were designed to survey the area inhabited by those dolphin species affected by the tuna fishery. Both the NOAA ship David Starr Jordan and the NOAA ship Townsend Cromwell were used to survey this area from Jan-Mar of 1976, 1977, 1979, and 1980; the Jordan alone was used in Oct-Nov 1977, from May-Jun 1982, and from Jan-Mar 1983 [1]. Cruise tracks are shown in Fig. 1. The areas surveyed varied somewhat from year-to-year: cruises in 1977 concentrated effort on the outer boundary of dolphin ranges; cruises in 1979 extensively surveyed the inshore calibration area (an area used to calibrate aerial and ship sighting rates, Holt and Powers, 1982) and (for the Cromwell) along the equator; the 1980 and 1982 cruises surveyed the calibration area and offshore around 10° north latitude; and the 1983 cruise surveyed the calibration area and along 10° south latitude [1]. The portion of the 1983 Jordan cruise, in which a helicopter was used in a sighting experiment, is not considered here.

During searching hours, two observers searched the seas ahead and to the side of the ship for signs of marine mammals using 20-25 power pedestal mounted binoculars. The observers rotated every 20-60 minutes with off-duty personnel to avoid fatigue. The ships approached the animals that were sighted to make species identifications and school size estimates. Data collected for each sighting included the time, date, and position of the sighting; the sea state at the time of the sighting; the angle from the ship's track and the estimated distance to the sighting; the initial cue that drew the observer's attention to the sighting (splashes, birds, or the mammals

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[1] Cruise reports available from NOAA, NMFS, Southwest Fisheries Center. Reference numbers for cruises are 168, 169, 213, 214, 319, 463, 464, 598, 599, 801, and 843.

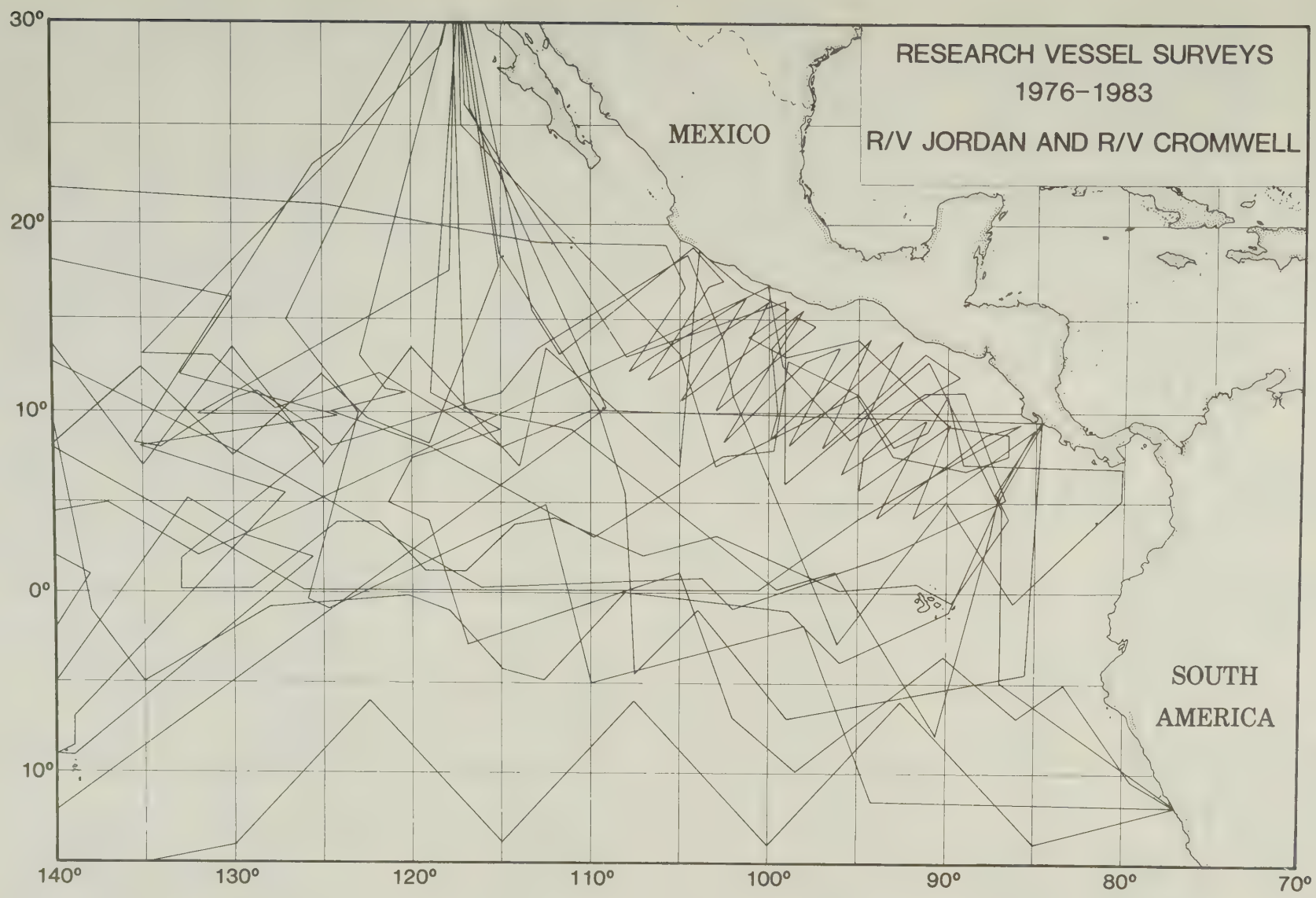

Figure 1. Survey tracks for the 1976, 1977, 1979, 1980, 1982, and 1983 research vessel cruises of the R/V Jordan and R/V Cromwell.

themselves); the observers' estimates of school size; and an estimate of the percentages of each species present in the school. Three different values were recorded for school size: a best estimate, a low or minimum estimate, and a high or maximum estimate.

On cruises from 1976 to 1980, school sizes and species proportions were a consensus estimate by all observers on a cruise. In 1982-83, school sizes and species proportions were recorded independently for each of 1 to 6 observers. These individual estimates of school size and species proportions were averaged to give a single, concerted estimate for each sighting. In cases where observers recorded conflicting species identifications, a panel of experts in marine mammal identification (A. C. Myrick[2], W. F. Perrin[2], and M. D. Scott[3]) reviewed the sighting forms and conferred with cruise leaders to arrive at concerted estimates. The panel considered each observer's drawings, photographs, written narratives, and experience in determining speices identifications.

Tuna Vessels

Tuna vessel data used in this report were gathered on 483 cruises during 1976-82. The observers were placed aboard tuna vessels by NMFS to gather data on sightings (similar to research vessel data), as well as data on tuna-net mortality and dolphin life history. When the observer was actively searching under good sighting conditions (usually using 7 power hand held binoculars), sightings were recorded as being "on effort." These included many sightings that were first observed by the tuna vessel crew using 20-25 power binoculars and then pointed out to the technician. The observer also recorded data on schools detected by the crew while the observer was not searching. These sightings were designated as occurring "off effort." The technicians recorded crew estimates of school sizes and species proportions, but crew identifications were typically general, so only the technicians' estimates were used in our study. The decision to investigate schools at close range (which greatly facilitates species identification) was made by the ships' personnel, and may have been influenced by the appraised likelihood of finding tuna.

Vessel Comparisons

There were several major differences in the way the sighting data were collected by observers aboard research and tuna vessels. First, research vessels followed planned cruise tracks, while the search patterns of tuna vessels were determined by the perceived availability of tuna and operational logistics (port call, breakdowns, etc.). Second, once a dolphin sighting was made, research vessels pursued the school of dolphins until a definitive species identification was made, whereas on tuna vessels the decision to pursue a school was more related to the perceived availability of tuna. Not all schools were approached by tuna vessels

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[2]Affiliated with NOAA, National Marine Fisheries Service.

[3]Affiliated with the Inter-American Tropical Tuna Commission.

for accurate species identification. Third, only one technician was aboard a tuna vessel versus 2-6 observers on duty aboard research vessels. School sizes and species proportions from tuna vessels were a single person's estimate rather than a consensus or a concerted estimate, as they were for research vessels. Finally, ship-based helicopters were occasionally used by tuna-vessel crew to make initial sightings (observer estimates of species composition and school size were made from the deck of the vessel, not the helicopter), whereas none of the research vessel sightings included here were made from a helicopter.

Sighting data from both of these vessel types share some weaknesses. The angles and distances to a sighting were usually rough estimates. Angles were judged by eye or from changes in ships heading. They show clustering around certain values (eg. 0^{o}, 30^{o}, 45^{o}, etc.) (Fig. 2a,b), which is attributed to rounding of values. An exception was the 1982-83 research vessel cruises where a calibrated collar on the binocular mount was used to read angles more precisely (Fig. 2c). Distances were estimated by eye or from transit time and were usually rounded to the nearest nautical mile (Fig. 3a,b). Again the 1982-83 research cruises were an exception; distances were estimated from the angle between the mammals and the horizon using ocular reticles (Fig. 3c). Estimates of school size and species composition were subject to similar rounding problems.

ANALYTICAL PROCEDURES

Species proportions were calculated for each of the 5 species and for a sixth category that included unidentified dolphins. The total number of dolphins sighted in each of these species categories for a given area was calculated by multiplying the observer's best estimate of school size for each sighting by the observer's estimate of the species proportions and summing this product for all the sightings within that area. Proportions were computed by dividing the estimate of the total number of individuals seen for each species category by the total for all 5 (or 6) categories. When unidentified dolphins were excluded, no attempt was made to prorate their numbers into any of the other 5 categories.

Geographic stratification was based on 5^{o} latitude by 5^{o} longitude squares. Greater than 99% of all sightings fell in 51 of the 5-degree squares (Fig. 4), and the remainder was lumped into an "other" category. Sightings made north of 25^{o} north latitude were not included in the calculation of species proportions since this area is outside the range of spotted and spinner dolphins (Perrin et al. 1983).

Overall species proportions were estimated from the 5-degree geographic strata by a weighted average of the proportions within the individual strata. An estimate of the relative abundance of all dolphin species within a 5-degree square was used as the weighting factor for each square. Relative dolphin abundance was estimated as the number of dolphin schools encountered per 100 nautical miles (NM) of searching effort by tuna vessels (Fig. 4, data for 1977-80 from T. Polacheck, methods presented by Polacheck, 1983). For comparison, species proportions were also calculated

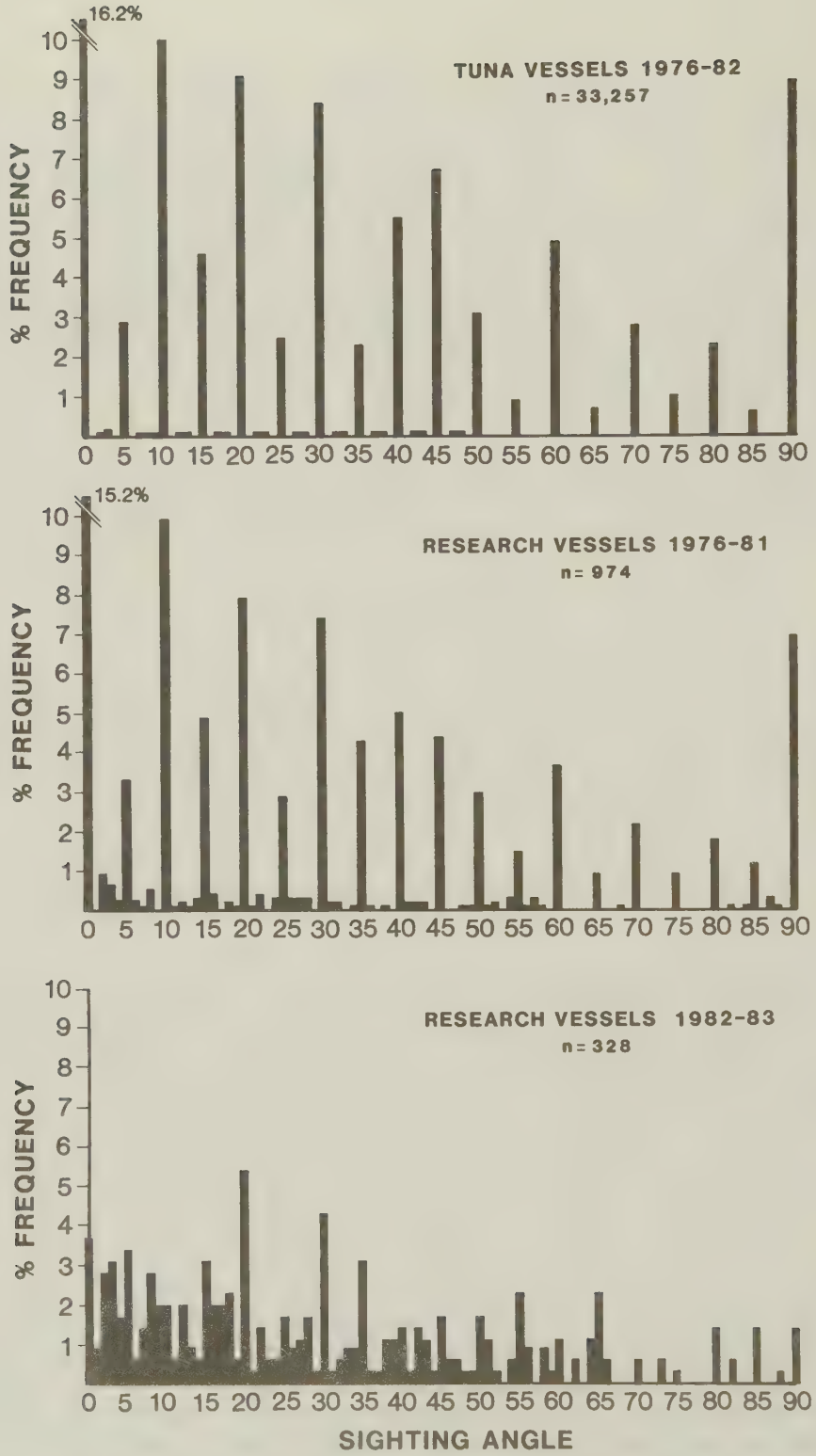

Figure 2. Distribution of estimated sighting angles from ships' headings to dolphin schools at the time of initial sightings for a) tuna vessels 1976-82, b) research vessels 1976-81, and c) research vessesls 1982-83.

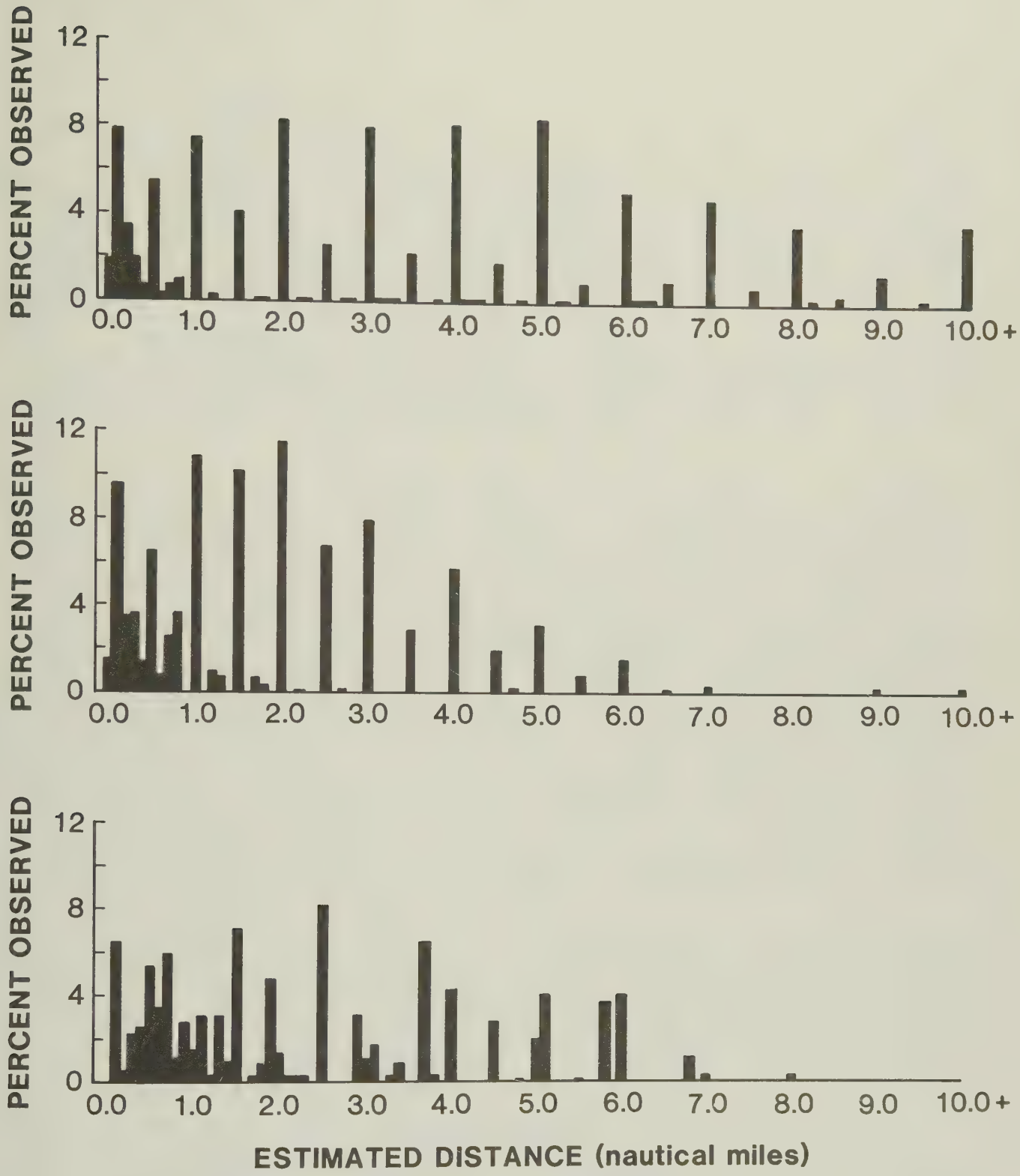

Figure 3. Distribution of estimated radial distances from ship to dolphin schools at the time of initial sightings for a) tuna vessels 1976-82, b) research vessels 1976-81, and c) research vessels 1982-83.

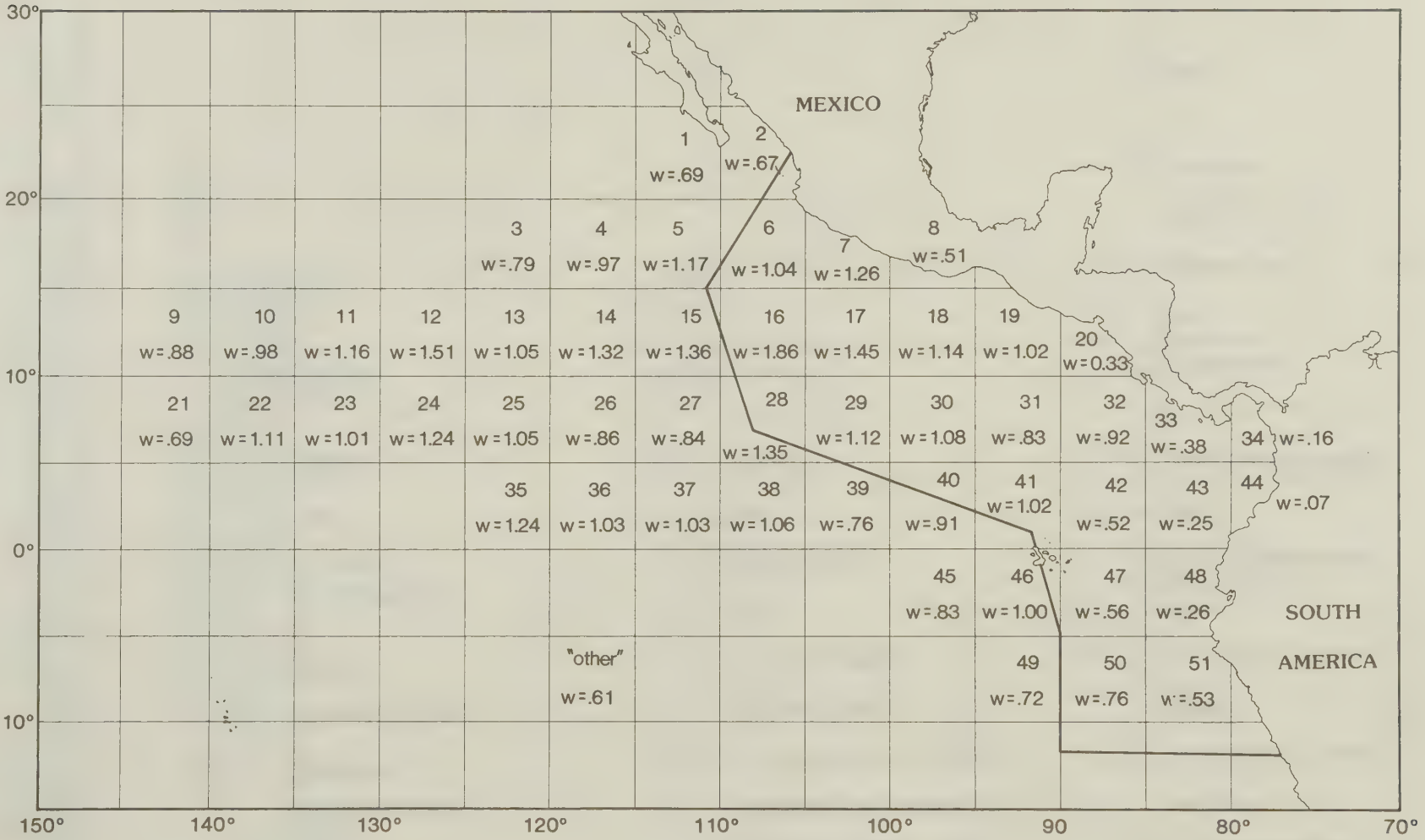

Figure 4. Weighting factors, w, used for computing weighted average of species proportions for 51 5-degree squares. Weightings are based on rate of encounter for dolphin schools per 100 search miles, multiplied by the proportion of each area which is covered by ocean. Bold line denotes the 1979 aerial survey area.

from an unweighted average of the proportions within 5-degree squares.

Ten factors were examined to determine their effect on overall species proportions. These were vessel type (tuna versus research), year, season, sighting cue, sea state, school size, effort (whether a sighting was made while the observer was actively search), sighting platform (helicopter versus ship), perpendicular sighting distance, and distance from the last sighting. The bases for stratifying the latter three are explained below.

Perpendicular distance refers to the normal distance from the school to an imaginary line along which the vessel was traveling at the time of the sighting. Perpendicular distance, d, was computed from the estimates of sighting angle, a, and radial distance, r, as

$$d = r \cdot \sin (a) \qquad (1).$$

As mentioned above, sighting angles and distances were subject to considerable imprecision due to rounding. An inordinately large number of sighting angles were recorded as zero (i.e. on the track line), which resulted in a large number of zero perpendicular distance estimates. In order to compensate for this bias the distribution of sighting angles was smoothed by adding a uniformly distributed random number between +5 and -5 degrees to each sighting angle. Similarly, the distribution of radial distances was smoothed by adding a random number between +0.5 and -0.5 nautical miles to each sighting distance. Examination of the distributions of sighting angles and distances (Figs. 2 & 3) indicates that this level of smoothing is appropriate for the observed rounding error. Perpendicular distances were computed from these smoothed angle and distance measures. This technique has been referred to as "smearing" in line transect work on marine mammals (Butterworth, 1982; Hammond and Laake, 1982). During 1976 tuna vessel cruises, sighting angles were often measured after the vessel turned towards the dolphin school; thus, perpendicular distances from 1976 tuna vessel cruises were not used.

Distance from the last dolphin sighting was calculated using latitude and longitude positions. Degrees and minutes were converted to degrees and hundredths of degrees, and straight-line distances were estimated using the Pythagorean theorem. For simplicity, distances were rounded to the nearest degree, and degrees of latitude and longitude were considered equivalent.

Testing Differences

A Monte Carlo technique known as bootstrap (Efron, 1979) was used to test the statistical significance of differences observed in the species proportions between two or more groups. The null hypothesis of this test was that all sub-samples could have been drawn randomly from the set of pooled sightings. The method involves empirically determining the probability that a more extreme difference in species proportions could have been drawn randomly from the pooled set of sightings. This corresponds to alpha, the probability that a true null hypothesis will be rejected (Type I error).

The methods used here are best illustrated with an example. Assume we have 100 sightings of which 25 were taken in 1977 and 75 in 1978. We wish to test whether the species proportions observed in these two years were significantly different. From the pooled set of 100 sightings, 25 would be selected randomly and species proportions would be calculated separately for these 25 and for the 75 remaining sightings. An index of dispersion would be used to measure the difference between the species proportions in the two groups. This process of selecting random groups would then be repeated many times in order to empirically determine the distribution of the chosen index. The observed dispersion statistic from the comparison of species proportions for the 1977 and 1978 sightings could then be compared with the empirically-determined distribution of that statistic in order to infer probability levels.

The choice of a statistic to act as an index of differences in species proportions is somewhat arbitrary. In this report, a sum of squared deviations was used. The statistic, X, was computed as

$$X = \sum_i \sum_j (E_i - O_{ij})^2 \qquad (2),$$

where E_i is overall proportion of species i, and O_{ij} is observed proportion of species i in group j. X is thus a sum of squared deviations of the observed species proportions in the groups from their expected values.

The simple example above is made more complicated if geographic differences in species proportion are considered. For instance, the 1977 sightings could have been made in areas where one species dominated and the 1978 sightings could have been made in another area where a different species dominated. In order to test for real differences between years rather than geographic differences, the sub-sampling would have to be done on a finer geographic scale. For this reason, random sub-sampling was applied to the pooled sample within 5-degree squares. The null hypothesis would thus be that the observed overall species proportions could have been drawn randomly from the total sample if random sampling occurred within geographic strata.

Multiple testing presents a problem in interpreting any analysis that involves a number of one-way comparisons. The true alpha level for a series of "n" independent tests is approximated by α / n, where α is the effective alpha level that is desired. The rejection criterion for the 17 tests presented here would make the rejection of any single null hypothesis very difficult if all tests were performed simultaneously. Instead, we have structured the tests hierarchically in the ranked order of perceived importance. Thus the effect of vessel type was tested at $\alpha = 0.05$. Perpendicular distance effects for both vessel types were tested next with $\alpha = 0.05 / 3$ (note: n = 3 because there was one first-rank test and two simultaneous, second-rank tests). Sighting cue for both vessel types was tested next with a rejection level of $\alpha = 0.05 / 5$. The observed probability of subsequent tests are reported without attempting to interpret significance. This was done because of the rapidly decreasing ability to discriminate a false null hypothesis, plus complications imposed by lack of independence between tests. Multi-way tests were not considered

because methods for these have not been developed.

Variances in Species Proportions

Imprecision in estimation of species proportions could result from at least two different sources. First, due to random error, the sample of dolphin schools encountered by survey vessels may not be truly representative of the entire population of dolphin schools. Second, species compositions and school sizes of sightings are themselves estimates, and as such, they are subject to error. Different methods were used to address these two sources of imprecision.

Sampling Error

Variance due to random sampling error was examined using another bootstrap method. We created estimates of species proportions within each 5-degree square by randomly sub-sampling from aggregate group of sightings. If 100 sightings were actually seen in a given square, sub-samples of 100 would be drawn from the aggregate sample (with replacement). This was repeated for all 52 geographic strata, and overall species proportions were calculated as above from weighted averages of proportions within geographic strata. If the aggregate sample is large enough to adequately represent the distribution of sightings in the underlying population, sub-sampling in this manner can be used to estimate variances or confidence limits (Efron 1982). In this application, variances were calculated from 200 randomly selected sub-samples in each of the 52 geographic strata.

The variances that we calculate by this method do not exactly correspond to the variance in our averages of 5-degree squares (as reported in Tables 1-8). Ideally we would have designed this bootstrap approach to create estimates for a given 5-degree geographic strata by randomly sub-sampling only those sightings occurring within that strata. Unfortunately, with the 5-degree stratification sample sizes would be insufficient to ensure that the underlying distribution of species composition is represented by the sightings in each strata. Variance estimates would be too conservative.

Given the methods described above, variance in species proportions will tend to be overestimated if the distribution of species proportions is geographically heterogeneous. The estimates of species proportions within 5-degree squares are drawn from the aggregate population of sightings, rather than from a more limited, local population of sightings. The method does not, however, include variability due to error in estimating the relative abundance weightings, nor does it include variation due to error in estimating the school sizes and species compositions of individual sightings (see below). We therefore believe that our variance estimates are more likely to be underestimates.

Means and standard errors were calculated for species proportions of three geographic areas which correspond to the statistical areas used in previous dolphin population estimations (Holt and Powers 1982). These areas are 1) inside the 1979 aerial survey region, 2) outside that region

and north of the equator, and 3) outside that region and south of the equator (Fig. 4). For comparison with previous estimates, only sightings with an estimated school size greater than 15 were included.

Observer Error

Imprecision also results from inaccuracy in estimating the species composition and school size of a sighting. Two observers may see the same schools and yet arrive at different estimates of overall species proportions. Some data have been collected on this type of variability from the 1982 and 1983 research vessel cruises.

On 1982 and 1983 research vessel surveys the observers were divided into two teams of three people. Each cruise had one team whose members had previous experience on tuna vessels and one team whose members had previous experience on research vessels. Members of the same team always worked together, rotating duty with the other team. Frequently all three members of a team were able to give independent school size and species composition estimates for a given sighting. These data were used to calculate the overall species proportion for each individual observer on the subset of his sightings that were seen by all members of his team. This yielded three independent sets of estimated species proportions for the same set of sightings. Means and standard errors were calculated for the proportions of spotted, spinner, common, and striped dolphins for all 4 teams.

Nearest Neighbor Analyses

A simple type of nearest neighbor analysis was used to examine spatial heterogeneity on scales finer than 5-degree squares. If all species are distributed randomly within an area, the probability of sighting a given school type will be independent of the previous school seen. If schools of the same species tend to be spatially aggregated, the probability of sighting a given species becomes contingent on previous sightings.

Because schools often contained more than one species, schools were classified by the mix of species present. The categories used were >90% spotted, >90% spinner, >90%common, >90% striped, >90% spotted plus spinner, and "other mixed" schools.

Sightings were considered adjacent if they were made on the same cruise and in the same 5-degree square. The number of sightings in each of the above categories was tallied, contingent on the category of the previous sighting (thus creating a 6 x 6 contingency table). The elapsed time and distance between sightings was not considered. The significance of differences in species proportions was tested using chi-square contingency tests (for n x n comparisons) and Fisher's exact test (for 2 x 2 comparisons). Categories were excluded from the chi-square test if cell frequencies fell below 5. Fisher's exact test was performed only if all marginal totals were greater than 5 and if the grand total was greater than 20.

RESULTS

The geographic distributions of species proportions are illustrated in Fig. 5 (from research vessels) and Fig. 6 (from tuna vessels) for the five species. Geographic differences can be seen in the relative proportions of these species. Proportions in the 5-degree squares show positive correlations between research and tuna vessels (r^2 = 0.43, 0.37, 0.57, and 0.59, respectively, for spotted, spinner, common, and striped dolphins). Research and tuna vessel data show similar patterns of species distibution.

Overall species proportions were calculated as weighted and unweighted averages of the 5-degree strata (Table 1). Despite similarities in gross patterns, large differences are evident in the overall distribution of species sighted from research vessels and tuna vessels. Research vessel sightings show a lower fraction of spotted dolphins. Also there are consistent differences between the weighted and unweighted averages, with the fraction of spotted dolphin being lower in the unweighted estimates.

Bootstrap methods show that the differences between research and tuna vessel proportions are highly significant ($p < 0.01$). From the bootstrap distribution of X, it can be seen that the observed value of X would be extremely unlikely if that sample were drawn randomly from the (geographically stratified) aggregate sample (Fig. 7).

The overall species proportions given in Table 1 may be biased by factors that affect the sightability of different species. For example, species with larger school sizes may be seen at greater distances and hence may be over-represented in the samples. Nine such factors were considered. Results of statistical tests of the factors are summarized in Table 2 and are considered individually below.

The species composition of sightings can be seen to change markedly with the perpendicular distance from a school to the ship's trackline (Table 3). For both research and tuna vessels, sightings made at greater perpendicular distance tend to have a larger proportion of spotted dolphins. From bootstrap simulations, these differences were not significant ($\alpha = 0.05/3$) for research vessel data ($p = 0.83$)(Fig. 8) but were significant for tuna vessel data ($p < 0.01$) (Fig. 9). Spotted dolphin schools are apparently visible at greater distances, which would lead to a biased estimate of species proportions. We attempted to eliminate this bias by including only those sightings from tuna vessels that were made within an estimated 3 NM of the trackline of the ship (note: for tuna vessels, sightings made within 3 NM of the trackline do not show a significant distance effect, and sightings within 4 NM do show significant differences). Subsequent calculations from tuna vessel data will therefore only include sightings made within an estimated 3 nm of the trackline of the ship.

Species proportions differ when stratified by sighting cues (Table 4). Percentages of spotted dolphins are higher when the initial sighting cue is the presence of sea birds. These differences are significant for both tuna

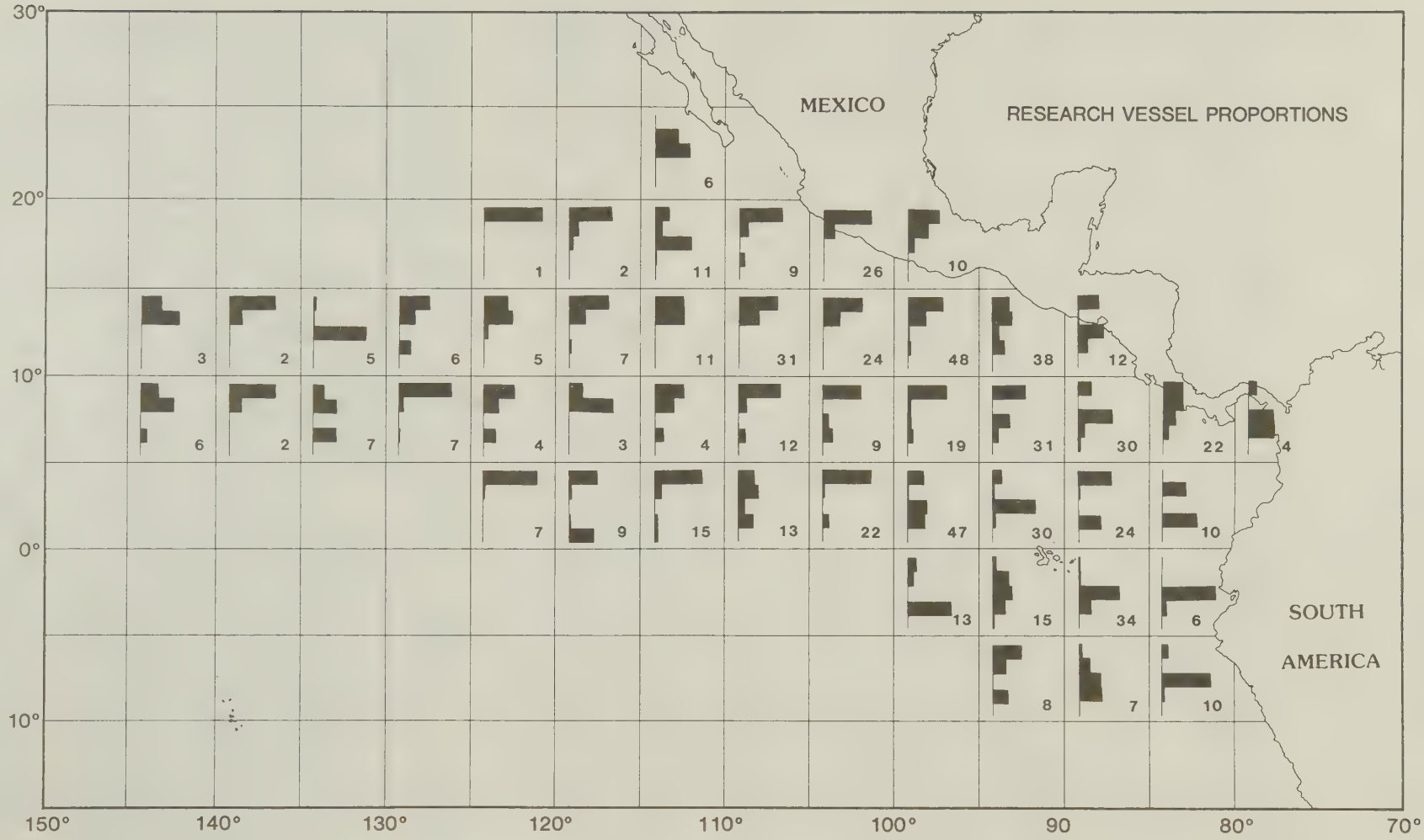

Figure 5. Geographic distribution of species proportions from research vessels stratified by 5-degree squares. Bars indicate relative percentages of spotted, spinner, common, striped, and Fraser's dolphins (from top to bottom). Numerals indicate number of sightings.

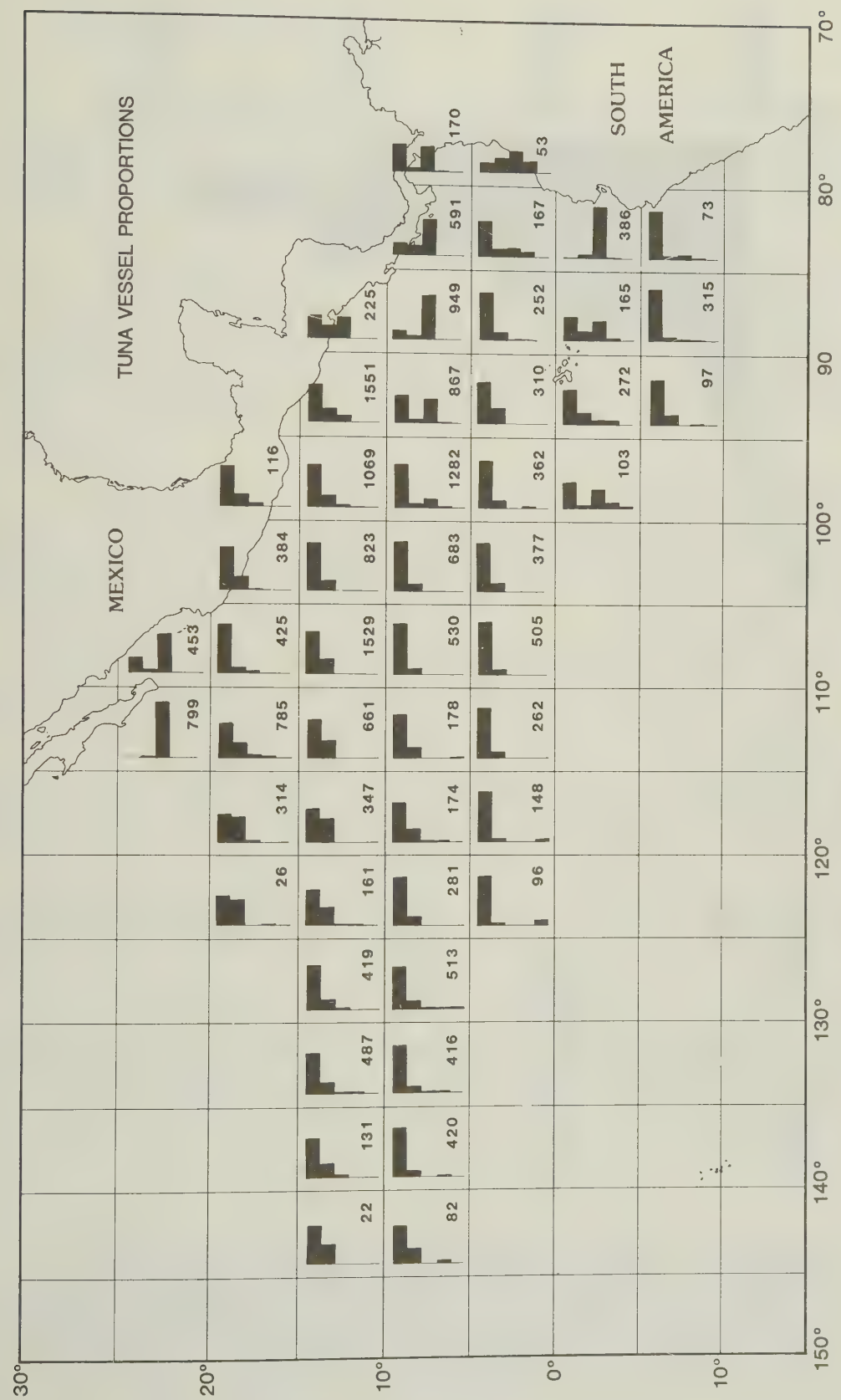

Figure 6. Geographic distribution of species proportions from tuna vessels stratified by 5-degree squares. Bars indicate relative percentages of spotted, spinner, common, striped, and Fraser's dolphins (from top to bottom). Numerals indicate number of sightings.

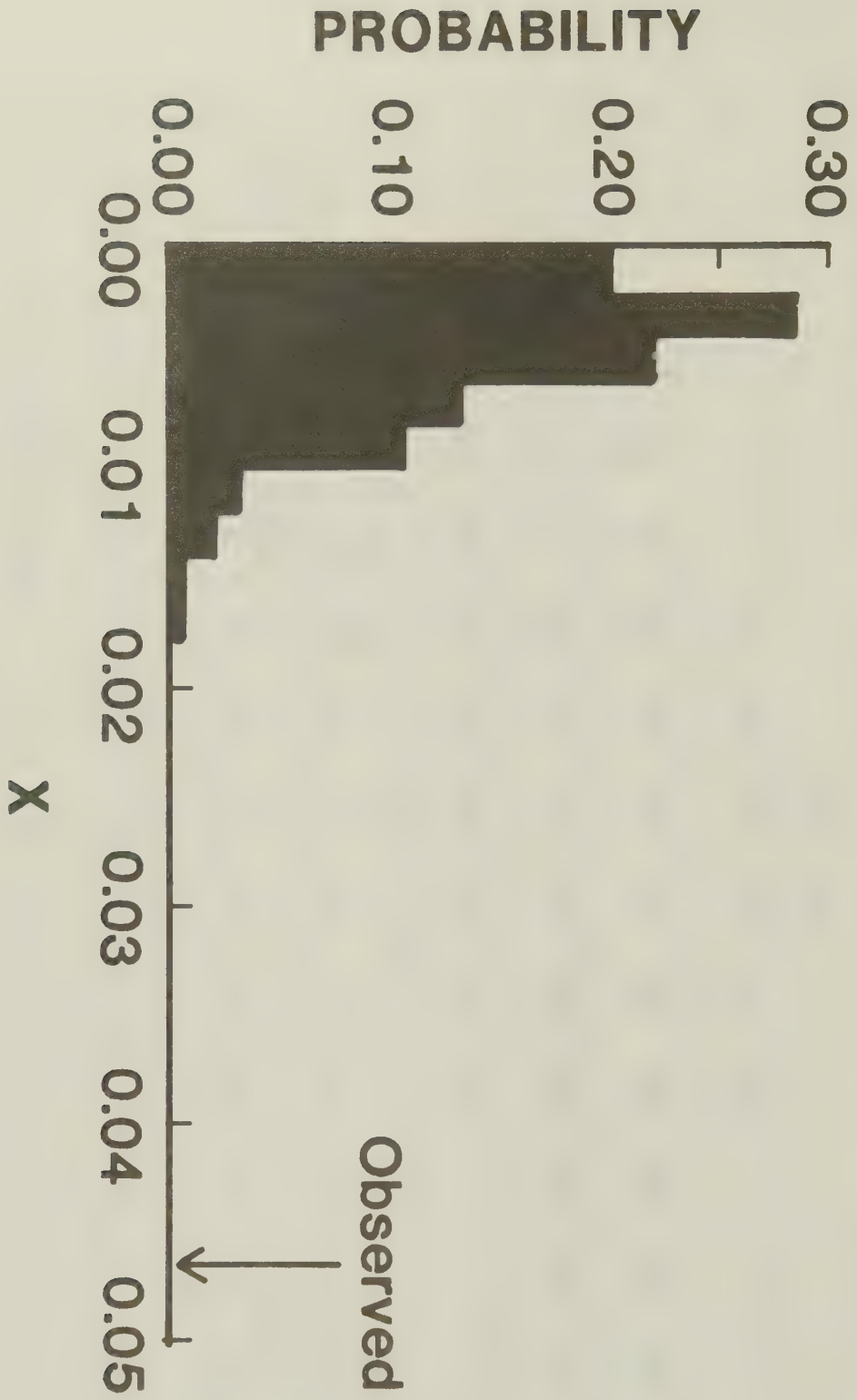

Figure 7. Empirically derived distribution of X from bootstrap test of whether species proportions from tuna and research vessels are significantly different. Arrow denotes X value of observed tuna vessel vs. research vessel comparison.

and research vessel sightings ($p < 0.01$, $\alpha = 0.05/5$) (Figs. 8 and 9).

Species composition in schools was found to be dependent on school sizes (Table 5) for research vessel ($p < 0.01$)(Fig. 8) and tuna vessel ($p < 0.01$)(Fig. 9) observations. For both, the larger schools tend to be dominated by spotted dolphins and smaller schools have proportionately more striped and common dolphins.

The distributions of species proportions by year are given in Table 6 for tuna and research vessel sightings. The geographic coverage for research vessels in any single year is insufficient for providing an accurate estimate of overall species proportions. Bootstrap tests show that the annual differences for tuna vessel sightings probably did not result from random variation ($p = 0.02$)(Fig. 9). Although the differences are slight, 1979 showed a higher fraction of common dolphins in the tuna vessel sightings.

Sea state was classified into four strata based on the Beaufort scale: 0 - 1, 2, 3, and 4+. Beaufort number increases with sea state, so the first group corresponds to the best sighting conditions. The difference in species proportions with sea state was larger for research vessels ($p < 0.01$) than for tuna vessels ($p = 0.10$)(Table 7).

Variation in species proportions between the four quarters of the calendar year (Table 8) is greater for tuna vessels ($p = 0.04$) than for research vessels ($p = 0.97$).

Tuna vessel sightings were stratified on the basis of whether the observer was on effort or off effort at the time of the sighting (Table 9). The differences in species compositions between these two categories are slight ($p = 0.80$)(Figs. 8 and 9).

Species proportions appear to be independent of the straight-line distance from the last sighting (Table 10) for both tuna vessels ($p = 0.92$)(Fig. 9) and research vessels ($p = 0.87$)(Fig. 8).

Relatively few tuna vessel sightings were initially made from a helicopter accompanying a tuna vessel (325 sightings, Table 11). Of the schools that were sighted, a disproportionate number were spotted dolphin schools. Perhaps due to small sample size, this effect was not significant ($p = 0.14$)(Fig. 9).

Variances

Standard errors were estimated for the species proportions from research and tuna vessels in the three geographical areas described above (Tables 12 and 13). In previous studies, a weighting factor (the inverse of the logarithm of school size) to adjust species proportions for the effects of differential sightability with perpendicular distance and school size (Holt and Powers, 1982). To compare our results with previous studies, we have calculated species proportions and standard errors using this weighting (Tables 14 and 15).

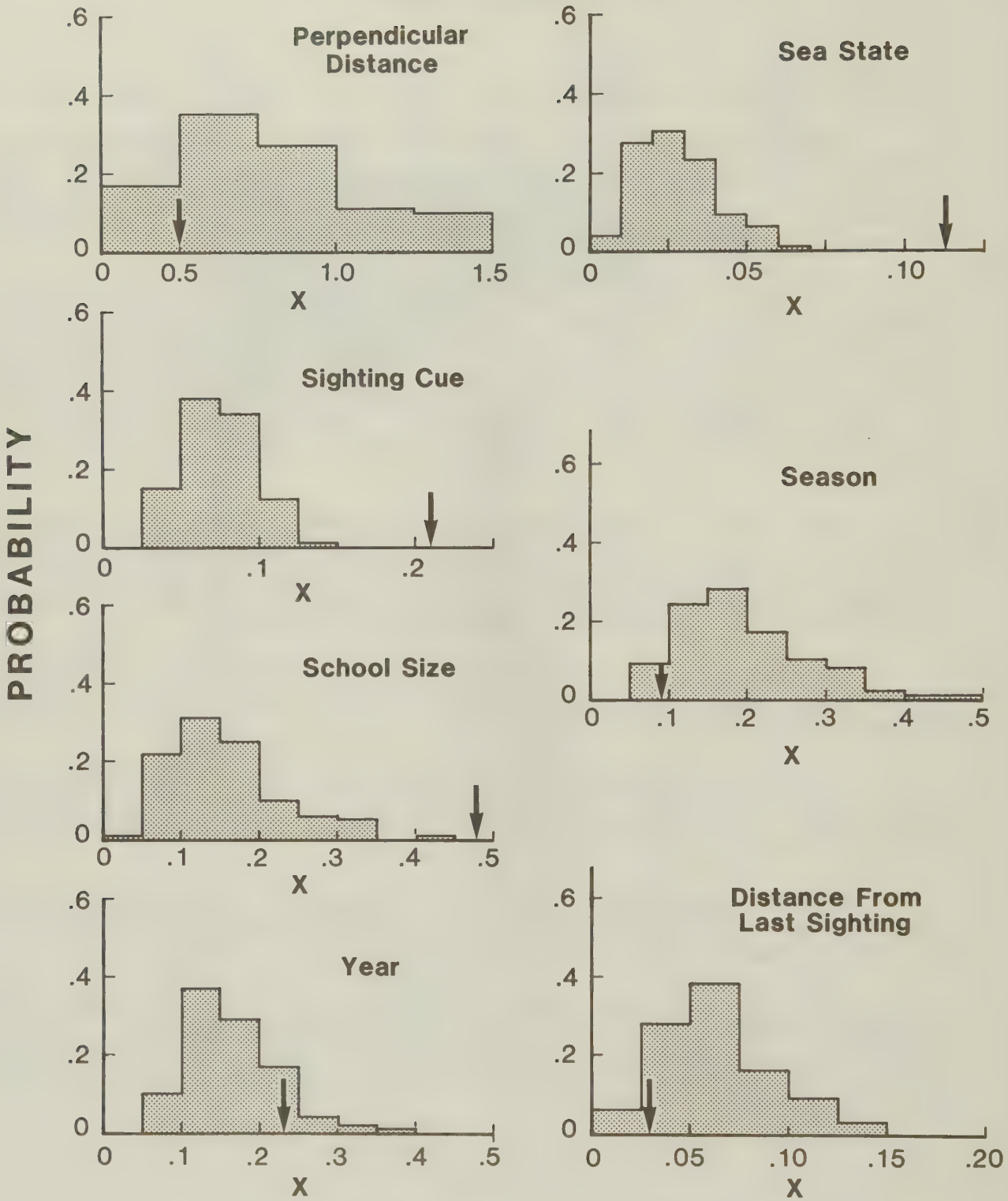

Figure 8. Empirically derived distributions of X from bootstrap tests of whether species proportions within different strata of the indicated factor are significantly different for research vessel sightings. Arrows denote observed values for the indicated test.

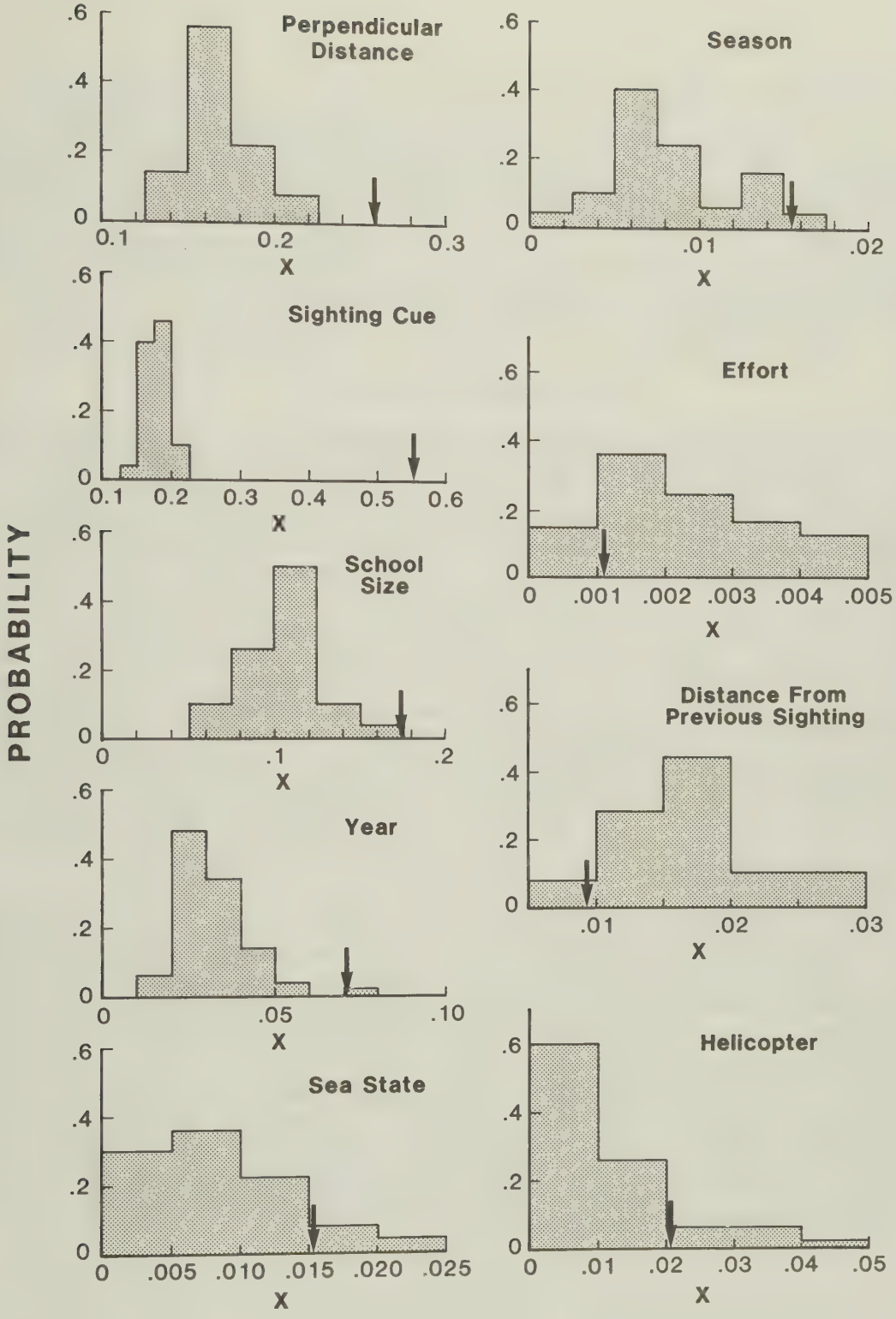

Figure 9. Empiracally derived distributions of X from bootstrap tests of whether species proportions within different strata of the indicated factor are significantly different for tuna vessel sightings. Arrows denote observed values for the indicated test.

Standard errors were also computed for the species proportions from the 1982 and 1983 research vessel sightings for which all members of a sighting team were able to make estimates (Table 16). Imprecision resulting from observer variability in estimating school sizes and compositions was small. Given the much greater variability in proportions due to sampling error (even with much larger sample sizes, Table 12), observer variability can be considered negligible.

Geographic Heterogeneity

The presence of geographic heterogeneity in species proportions was tested with the nearest neighbor analysis described above. Large-scale differences were tested by pooling sightings in all areas. The proportion of schools of a given type contingent on the type of the previous school are tabulated in Table 17 for all tuna and research vessel sightings. For the tuna vessel observations, the differences in species proportions were highly significant ($\chi^2_{25} = 8916$, $p << 0.001$). In particular, it may be noted that the percentages along the principal diagonals of these matrices (underlined values in Table 17) are consistently greater than the overall percentages of the given school types. Sample sizes for research vessel observations were too small for the chi-square test, but again the values on the principal diagonal are consistently greater than the overall species percentages. Thus it can be concluded that the probability of sighting a given school type is enhanced if the previous school was of the same type. This result is consistent with the observation of large scale geographic heterogeneity (Figs. 5 and 6).

In order to examine geographic heterogeneity on scales that are finer than 5-degree squares, tests were performed on sightings pooled within 5-degree blocks. Because research vessel data is sparse when stratified on such a fine scale, tests were performed using only the tuna vessel data. Fisher's exact test was used to test whether the probability of sighting one species of dolphin is enhanced if the previous school were of the same type (1-tailed test). Tests were performed pairwise on school types because few 5-degree squares contained sufficient observations for multi-way comparisons. Results (Table 18) indicate that in an overwhelming number of cases, the probability of seeing a school of a given type is enhanced if the previous school was of the same type.

DISCUSSION

Bias and Precision

In order to obtain the best estimate of the overall species proportions for dolphins of the ETP, we wish to eliminate all biases in our sampling methods, while maintaining a large sample size to increase precision.

A variety of factors may be introducing bias into the calculation

of species composition from both research and tuna vessels sightings. The tacit assumption that has been made thus far is that sightability is the same for the five species. If some of the species are more visible than others, species proportions may be biased. School size, associated birds, and swimming behavior may all influence sightability. The validity of the assumption of equal sightability must therefore be examined.

The species composition of schools varies greatly with school size (Table 5). Large schools have a higher fraction of spotted dolphins and a much lower fraction of striped dolphins than small schools. Since large schools are more likely to be seen at a distance than small schools, this would tend to bias overall species proportions.

The presence of sea birds is commonly used as a sighting cue since birds, dolphin, and tuna are often closely associated. Bird flocks are most commonly associated with spotted dolphins and seldomly associated with striped dolphins (Table 4). Since birds may allow observers to detect schools at a greater distance, overall species proportions may be biased.

The dolphin species considered here also differ in swimming behavior. Common dolphins appear to swim exuberantly, with much jumping and splashing. Spotted and spinner dolphins tend to be more submerged and are less likely to jump unless frightened or chased. The behavior of these species often changes as they are approached by a vessel. Spotted and spinner dolphins have learned to "run" from vessels (Au and Perryman 1982). When swimming rapidly, these species become easier to spot. Hewitt (in press) found that schools are usually seen before this running behavior begins.

The species-specific differences in sightability are more likely to bias distant sightings than sightings that are made near a vessel. Schools that are on or near the trackline of a vessel are likely to be seen regardless of their composition. Bias from all three of the above factors can be minimized if samples are limited to those schools that would have passed close enough to the ship to guarantee detection. Surprisingly, research vessel sightings showed no significant difference in species proportions with perpendicular distance; hence there is insufficient justification for eliminating the distant sightings made from research vessels. However, additional data may cause a reconsideration of this point given that several characteristics of spotted dolphins (large school sizes and co-occurrence of birds) are likely to make them visible at greater distances.

Research vs. Tuna Vessels

Relatively large differences were seen between the species proportions from tuna vessel sightings and those from research vessel sightings. Similar differences have been noted in previous studies (Holt and Powers, 1982). In general, tuna vessel observations include a greater proportion of spotted dolphin sightings and fewer sightings of striped dolphin. We will attempt to explain these differences in terms of factors that affect sightings from the two vessel types. Although Our conclusions are speculative, we feel they are the most reasonable interpretation of

available data.

Since the differences in the overall estimates of species proportions from research and tuna vessels are too large to be random sampling error, alternative hypotheses must be examined. Given the large differences in species composition between geographic areas, the differences between vessel types may have resulted from large-scale differences in the areas searched. Alternatively, differences in the species seen could have arisen from differences in the searching methods used by tuna and research vessels. Finally, although the vessels may have been searching in the same large-scale areas, the observed differences could have resulted from fine scale geographic differences coupled with differences in search patterns between the vessel types. These hypotheses will be considered in detail below.

Area Effects

Although research and tuna vessels did not concentrated their searching efforts in exactly the same geographic areas, the areas surveyed by both covers most of the area inhabited by ETP dolphins. Unlike previous estimates of species proportions which did not consider geographic differences (Holt and Powers, 1982), the overall species proportions in this study were calculated as a weighted sum of species proportions in 5-degree squares. If all years are included, coverage was relatively complete for both vessel types. Since the calculation of overall proportions incorporated geographic stratification, large scale geographic differences in searching effort cannot explain these large differences in species composition between vessel types.

Searching Methods

Differences in searching methods between research and tuna vessels can cause differences in the estimates of species composition in a variety of ways. First, flocks of birds are visible at greater distances than are schools of dolphins, and tuna vessels are more likely to investigate bird flocks. In cases where sea birds were the initial cue for a dolphin sighting, the proportion of spotted dolphins was much higher. This was true for both research and tuna vessel sightings (Table 4). This indicates that sea birds are more likely to be associated with schools of spotted dolphins than with other dolphin schools. If tuna vessels change course to investigate bird aggregations, the proportion of spotted dolphins is likely to be exaggerated. Eliminating distant sightings should, however, prevent this from biasing species proportions.

Second, the initial sightings on tuna vessels are usually made by crew members. If the crew member decides that the sighting is not a worthwhile cue for the presence of tuna, the observer may not be made aware of the sighting or the vessel may not approach close enough for the observer to determine species composition or school size. The crew has the advantage of using 20-25x binoculars which greatly facilitate searching. The crew is mostly concerned with dolphin schools which may be associated with tuna. These typically include spotted dolphin schools, mixed schools of spotted and spinner dolphins, and ocassionally common dolphins. Consequently,

observers may be more likely to be told about sightings of these species than sightings of striped or Fraser's dolphins which seldom are associated with tuna. Crew members also make some observations which are recorded by the observer, but which the observer never gets a chance to verify. Such records were not used in our analyses because of their non-specific species identifications (such as "black fish", "whitebellies", etc.).

Geographic Heterogeneity

Although tuna vessels and research vessels searched in the same general geographic areas, their searching patterns differed greatly. Research vessels searched systematically, following pre-determined courses. Tuna vessels searched in areas where tuna were thought to be; in some cases "code groups" or cooperatives relayed radio information about fish availability (Croom, 1980). If dolphin species are distributed randomly within an area, search patterns are not likely to influence the overall species composition of sightings (ignoring the possibility of resighting the same school). If, however, the distribution of species is related to habitat and if searching effort is limited to areas with distinctive oceanographic or biological features (e.g. the presence of tuna), overall species compositions may be biased. Because the distribution of dolphin species is patchy, systematic or random search patterns are preferable.

The results of the nearest neighbor analysis indicate that schools with similar species composition are often found together. The cruise tracks of tuna vessels indicate that their search patterns are not random (Polacheck, 1983). Tuna vessels will usually search intensively in a localized area, and then move to another area and again search intensively. These patterns may take advantage of the tendency for schools of spotted dolphins to be spatially aggregated. Because dolphin species are not distributed randomly, this non-random search pattern used by tuna vessels is likely to result in biased estimates of species proportions, whereas the pre-planned search pattern of research vessels are less likely to result in such biases.

Sighting Efficiency

The difference between research and tuna vessels can be largely explained in terms of species specific differences in sighting efficiency. We define encounter rate as the number of schools sighted per 1000 survey miles. Overall encounter rate for research vessels in 1977-83 was approximately 10.0 for all 5 species (Holt [4], Table 3). For research vessels, 56% of all schools included either spotted dolphins, spinner dolphins, or both species, 17% included common dolphins, and 25% included striped dolphins. The research vessel encounter rates for individual species are thus 5.6 / 1000 NM for spotted/spinner schools, 1.7 / 1000 NM for common schools, and 2.5 / 1000 NM for striped schools. For these species groups, the corresponding values from tuna vessels are 6.6, 0.9, and 0.4 / 1000 NM, respectively (Polacheck 1983, Table IX-3, data from 1977-80). These results indicate that research vessels are as effective as tuna vessels in sighting spotted dolphin schools, but they are much more

effective at sighting schools of common and striped dolphins.

Recommendations

Although tuna vessel data represent a far greater number of sightings, estimates of overall species proportions from tuna vessels sightings are probably biased because of the way the data were collected. Tuna vessels have been used as ships-of-opportunity. Research vessel cruises were designed to survey all dolphin species. Historically, the use of tuna vessel data for estimates of species proportions was largely motivated by the lack of sufficient data from research vessels. We believe that current research vessel data are sufficient to estimate species proportions.

Our best estimates are the research vessel proportions which were averaged over 5-degree geographic strata (Table 12). These estimates, however, they may be subject to errors from factors we have not considered and to inaccuracies resulting from random sampling error. It may be that certain species are less easily seen at all sighting distances.

Estimates given in Table 12 include species proportions from both weighted and unweighted averages of the proportions within 5-degree strata. We do not feel confident in recommending one method over the other. The weighting factors were derived from tuna vessel estimates of relative dolphin density. Since tuna vessels encounter proportionately more spotted dolphins, the relative density estimates may be biased toward areas where spotted dolphin abundance is high. However, areas of high spotted dolphin abundance may also be areas of high density for the other species. Unweighted averages might therefore underestimate the true proportion of spotted dolphins. If the abundance of other species is positively correlated with spotted dolphin abundance and if that correlation is imperfect (i.e. less than 1.0), the true species proportions probably lie between those estimated by the weighted and unweighted averages.

Previous estimates of species proportions for ETP dolphins have used entirely different methods (Holt and Powers, 1982); thus, our results are not directly comparable with previous ones. Holt and Powers used a method that averaged percentage compositions in a school, without weighting by school size. In effect, this gave an average species composition of schools rather than a percentage of individuals belonging to the various species (as in our estimates). Because spotted dolphins tend to form large schools, our estimates would tend to show a higher proportion of spotted dolphins than these previous estimates. Our current estimates of the percentage of spotted dolphins (Table 12) fall between the previous estimates for research vessels and those for tuna and research vessels pooled (Holt and Powers 1982, Table 21).

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[4]Holt, R. S. 1984. Estimation of density of dolphin schools in the eastern tropical Pacific Ocean using line transect methods (Manuscript).

SUMMARY

In order to prorate estimates of dolphin density from aerial surveys to population estimates for species, an overall estimate of dolphin species proportions is needed. Sighting observations from surface vessels can be used for this purpose if these sightings are representative of the actual species mix in the ETP.

Tuna vessel sightings are unacceptable for this purpose for three reasons. First, tuna vessels are primarily interested in dolphin species that are likely to be associated with tuna. The crew may not relay information on sightings of other species to the observer. Second, tuna vessels will approach those dolphin schools that are likely to be associated with tuna. The observer may never get an adequate look at other schools to estimate species composition or school size. Third, tuna vessels search non-randomly in areas that are believed to have tuna. Dolphin species are not randomly distributed, rather schools of like species are found clustered together. The distribution of dolphin species is likely to be related to the same oceanographic features that determine tuna distributions. Therefore systematic or pre-planned search patterns are necessary to avoid biased species proportions.

The best estimates of species proportions (Table 12) are therefore derived from research vessel observations. Because research vessel searching effort is not uniformly distributed geographically, estimates of species proportions are best averaged over small geographic strata. Ideally this averaging should be weighted by the total density of dolphins within each strata. Tuna vessel encounter rates can be used for this purpose, but these estimates of relative density may be skewed towards areas of spotted dolphin abundance. Values from unweighted and weighted averages of geographic strata probably bracket the true estimates of ETP dolphin species proportions.

ACKNOWLEDGEMENTS

We wish to acknowledge the efforts of the many technicians who were responsible for gathering the data upon which this report is based. The sightings used here are the result of literally hundreds of man-years of labor, often under difficult circumstances. Acknowledgement is also deserved by the data editing and management group and the graphics department, SWFC. We thank Tom Polacheck for generously sharing his information on dolphin relative abundance. John Cologne provided data and analysis pertaining to the effects of observer error from 1982-83 research cruises. The statistical design used here benefited greatly from discussions with T. Gerrodette, D. Goodman, A. MacCall, and R. Methot. We thank G. Broadhead, P. Hammond, D. Chapman, J. Michalski, T. Quinn, G. Sakagawa, and T. Smith for their critical review of this manuscript.

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Table 1. Dolphin species proportions from tuna and research vessel sighting data. Values include both weighted and unweighted averages of the species proportions in 5-degree geographic strata.

Species	Tuna Vessels		Research Vessels	
	Weighted Average	Un-Weighted Average	Weighted Average	Un-Weighted Average
Identified				
Spotted dolphin	0.69	0.66	0.50	0.45
Spinner dolphin	0.19	0.18	0.23	0.22
Common dolphin	0.10	0.13	0.15	0.18
Striped dolphin	0.02	0.02	0.11	0.13
Fraser's dolphin	0.01	0.01	0.01	0.02
Total	1.0	1.0	1.0	1.0
Unidentified	0.13	0.15	0.07	0.07
Number of Dolphins	23,100,000		149,000	
Number of Schools	33,346		1,120	

Table 2. Bootstrap results testing the significance of various sighting factors on estimates of species proportions. Stratification of the sighting factors is described in the text. For each test, numbers represent the probability that observed species proportions in each of the strata could have been drawn randomly from a sample consisting of all strata pooled.

Sighting Factor	Research Vessels	Tuna Vessels	Tuna and Research Vessels Pooled
1) Vessel type	-	-	< 0.01
2) Perpendicular distance	0.83	< 0.01	-
3) Sighting cue	< 0.01	< 0.01	-
4) School size	< 0.01	< 0.01	-
5) Year	0.09	0.02	-
6) Sea state	< 0.01	0.10	-
7) Season	0.97	0.04	-
8) Effort	-	0.80	-
9) Distance from prev. sighting	0.87	0.92	-
10) Helicopter	-	0.14	-

Table 3. Dolphin species proportions from tuna and research vessel sighting data, stratified by a smeared estimate of the perpendicular distance from the school to the ship's trackline. Values are weighted averages of the species proportions in 5-degree geographic strata.

Species	Perpendicular Distance in Nautical Miles 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	> 8	Overall
TUNA VESSELS										
Identified										
Spotted dolphin	0.68	0.66	0.71	0.73	0.73	0.76	0.78	0.78	0.79	0.699
Spinner dolphin	0.18	0.19	0.18	0.17	0.17	0.17	0.14	0.16	0.19	0.180
Common dolphin	0.11	0.13	0.08	0.09	0.08	0.06	0.06	0.06	0.02	0.096
Striped dolphin	0.03	0.01	0.03	0.01	0.01	0.00	0.01	0.01	0.00	0.016
Fraser's dolphin	0.00	0.02	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.008
Total	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Unidentified	0.15	0.18	0.14	0.12	0.12	0.13	0.13	0.08	0.11	0.137
# of Dolphins	6,470K	3,290K	2.360K	1,840K	1,320K	860K	546K	310K	570K	17,600K
# of Schools	12262	4773	3053	2160	1510	983	618	374	570	17600
RESEARCH VESSELS										
Identified										
Spotted dolphin	0.45	0.39	0.66	0.60	0.43	0.39	-	0.30	-	0.493
Spinner dolphin	0.22	0.22	0.16	0.11	0.12	0.28	-	0.70	-	0.220
Common dolphin	0.13	0.22	0.08	0.20	0.18	0.17	-	0.00	-	0.145
Striped dolphin	0.19	0.17	0.10	0.09	0.27	0.08	-	0.00	-	0.127
Fraser's dolphin	0.02	0.00	0.00	0.00	0.00	0.07	-	0.00	-	0.014
Total	1.0	1.0	1.0	1.0	1.0	1.0		1.0		1.0
Unidentified	0.05	0.10	0.15	0.20	0.27	0.05	-	0.00	-	0.07
# of Dolphins	71K	37K	16K	11K	6.3K	2.2K	-	0.4K	_	144K
# of Schools	672	237	95	46	26	10	0	1	0	1087

Table 4. Dolphin species proportions from tuna and research vessel sighting, data stratified by the sighting cue. Values are weighted averages of the species proportions in 5-degree geographic strata. Tuna vessel sightings include only those whose smeared perpendicular distances are less than 3 nautical miles.

	Sighting Cue			
Species	Sea Birds	Splashes	Mammals	Overall
TUNA VESSELS				
Identified				
Spotted dolphin	0.73	0.51	0.50	0.682
Spinner dolphin	0.18	0.16	0.21	0.182
Common dolphin	0.07	0.23	0.18	0.106
Striped dolphin	0.01	0.09	0.07	0.022
Fraser's dolphin	0.00	0.01	0.04	0.008
Total	1.0	1.0	1.0	1.0
Unidentified	0.11	0.35	0.29	0.152
# of Dolphins	7,660K	1,730K	2,380K	11,800K
# of Schools	9335	3675	6538	19548
RESEARCH VESSELS				
Identified				
Spotted dolphin	0.61	0.39	0.39	0.504
Spinner dolphin	0.29	0.19	0.19	0.237
Common dolphin	0.08	0.13	0.13	0.123
Striped dolphin	0.02	0.29	0.27	0.120
Fraser's dolphin	0.00	0.01	0.02	0.016
Total	1.0	1.0	1.0	1.0
Unidentified	0.02	0.16	0.14	0.084
# of Dolphins	51K	15K	45K	111K
# of Schools	243	181	544	968

Table 5. Dolphin species proportions from tuna and research vessel sighting data, stratified by the observer's (s') estimate of total school size. Values are weighted averages of the species proportions in 5-degree geographic strata. Tuna vessel sightings include only those whose smeared perpendicular distances are less than 3 nautical miles.

Species	Total School Size 1-14	15-50	51-100	101-300	301-900	> 900	Overall
TUNA VESSELS							
Identified							
Spotted dolphin	0.38	0.51	0.57	0.65	0.70	0.68	0.682
Spinner dolphin	0.17	0.13	0.16	0.16	0.17	0.19	0.182
Common dolphin	0.21	0.19	0.15	0.13	0.10	0.11	0.107
Striped dolphin	0.22	0.15	0.11	0.06	0.03	0.01	0.022
Fraser's dolphin	0.02	0.01	0.00	0.00	0.00	0.01	0.008
Total	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Unidentified	0.73	0.55	0.44	0.27	0.15	0.13	0.153
# of Dolphins	14K	108K	179K	851K	2,570K	8,400K	12,100K
# of Schools	2437	3334	2065	3923	4538	3791	20088
RESEARCH VESSELS							
Identified							
Spotted dolphin	0.39	0.32	0.49	0.49	0.54	0.53	0.501
Spinner dolphin	0.02	0.11	0.17	0.30	0.20	0.17	0.225
Common dolphin	0.07	0.11	0.11	0.09	0.19	0.29	0.148
Striped dolphin	0.52	0.46	0.22	0.11	0.04	0.00	0.112
Fraser's dolphin	0.00	0.00	0.01	0.01	0.04	0.01	0.014
Total	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Unidentified	0.67	0.21	0.12	0.02	0.02	0.00	0.069
# of Dolphins	1.3K	10K	16K	36K	50K	37K	149K
# of Schools	249	332	208	204	103	24	1120

Table 6. Dolphin species proportions from tuna and research vessel sighting data, stratified by year. Values are weighted averages of the species proportions in 5-degree geographic strata. Tuna vessel sightings include only those whose smeared perpendicular distances are less than 3 nautical miles.

Species	Year 1976	1977	1978	1979	1980	1981	1982	1983	Overall
TUNA VESSELS									
Identified									
Spotted dolphin	-	0.68	0.67	0.70	0.72	0.70	0.68	0.57	0.682
Spinner dolphin	-	0.18	0.19	0.14	0.16	0.18	0.16	0.17	0.182
Common dolphin	-	0.11	0.11	0.14	0.09	0.09	0.09	0.17	0.107
Striped dolphin	-	0.02	0.02	0.02	0.02	0.02	0.06	0.09	0.022
Fraser's dolphin	-	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.008
Total		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Unidentified	-	0.13	0.19	0.16	0.17	0.19	0.20	0.29	0.15
# of Dolphins	-	4,360K	2,870K	2,010K	1,360K	647K	775K	91K	12,100K
# of Schools	0	5287	4711	4156	2322	1506	1836	270	20088
RESEARCH VESSELS									
Identified									
Spotted dolphin	0.34	0.45	-	0.40	0.53	-	0.54	0.41	0.501
Spinner dolphin	0.13	0.27	-	0.20	0.23	-	0.19	0.23	0.225
Common dolphin	0.32	0.09	-	0.17	0.07	-	0.08	0.14	0.148
Striped dolphin	0.21	0.16	-	0.23	0.17	-	0.19	0.21	0.112
Fraser's dolphin	0.00	0.03	-	0.00	0.01	-	0.00	0.01	0.014
Total	1.0	1.0		1.0	1.0		1.0	1.0	1.0
Unidentified	0.21	0.07	-	0.18	0.05	-	0.11	0.16	0.069
# of Dolphins	38K	34K	-	33K	15K	-	17K	12K	149K
# of Schools	143	180	0	291	207	0	135	164	1120

Table 7. Dolphin species proportions from tuna and research vessel sighting data, stratified by the sea state. Values are weighted averages of the species proportions in 5-degree geographic strata. Tuna vessel sightings include only those whose smeared perpendicular distances are less than 3 nautical miles.

Species	Beaufort State 0-1	2	3	> 4	Overall
TUNA VESSELS					
Identified					
Spotted dolphin	0.69	0.69	0.68	0.69	0.690
Spinner dolphin	0.13	0.17	0.17	0.18	0.157
Common dolphin	0.13	0.10	0.11	0.10	0.103
Striped dolphin	0.02	0.04	0.04	0.02	0.040
Fraser's dolphin	0.03	0.00	0.00	0.01	0.010
Total	1.0	1.0	1.0	1.0	1.0
Unidentified	0.17	0.18	0.18	0.18	0.170
# of Dolphins	937K	1,690K	1,470K	730K	4,830K
# of Schools	2097	3520	2920	1411	9948
RESEARCH VESSELS					
Identified					
Spotted dolphin	0.49	0.52	0.51	0.37	0.501
Spinner dolphin	0.14	0.20	0.17	0.26	0.214
Common dolphin	0.06	0.12	0.08	0.15	0.103
Striped dolphin	0.32	0.14	0.23	0.22	0.176
Fraser's dolphin	0.00	0.01	0.01	0.00	0.006
Total	1.0	1.0	1.0	1.0	1.0
Unidentified	0.16	0.10	0.17	0.16	0.105
# of Dolphins	12K	29K	23K	14K	77K
# of Schools	129	237	237	192	769

Table 8. Dolphin species proportions from tuna and research vessel sighting data, stratified by season. Values are weighted averages of the species proportions in 5-degree geographic strata. Tuna vessel sightings include only those whose smeared perpendicular distances are less than 3 nautical miles.

Species	Season Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Overall
TUNA VESSELS					
Identified					
Spotted dolphin	0.68	0.67	0.68	0.64	0.682
Spinner dolphin	0.14	0.17	0.19	0.20	0.182
Common dolphin	0.10	0.10	0.11	0.12	0.107
Striped dolphin	0.05	0.05	0.02	0.03	0.022
Fraser's dolphin	0.03	0.01	0.00	0.00	0.008
Total	1.0	1.0	1.0	1.0	1.0
Unidentified	0.17	0.17	0.13	0.24	0.153
# of Dolphins	2,690K	3,310K	3,850K	2,270K	12,100K
# of Schools	5553	5210	5667	3658	20088
RESEARCH VESSELS					
Identified					
Spotted dolphin	0.44	0.47	0.58	0.40	0.501
Spinner dolphin	0.24	0.18	0.12	0.30	0.225
Common dolphin	0.18	0.13	0.09	0.05	0.148
Striped dolphin	0.12	0.22	0.21	0.25	0.112
Fraser's dolphin	0.02	0.00	0.00	0.00	0.014
Total	1.0	1.0	1.0	1.0	1.0
Unidentified	0.06	0.09	0.20	0.18	0.069
# of Dolphins	116K	14K	6K	13K	149K
# of Schools	895	116	44	65	1120

Table 9. Dolphin species proportions from tuna vessel sighting data, stratified by whether the observer was "on effort" or "off effort" at the time of the sighting. Values are weighted averages of the species proportions in 5-degree geographic strata. Included are sightings whose smeared perpendicular distances are less than or equal to 3 nautical miles.

Species	"On Effort"	"Off Effort"	Overall
TUNA VESSELS			
Identified			
Spotted dolphin	0.67	0.69	0.682
Spinner dolphin	0.19	0.17	0.182
Common dolphin	0.11	0.10	0.107
Striped dolphin	0.02	0.04	0.022
Fraser's dolphin	0.01	0.00	0.008
Total	1.0	1.0	1.0
Unidentified	0.15	0.15	0.153
# of Dolphins	6,380K	5,740K	12,100K
# of Schools	10737	9351	20008

Table 10. Dolphin species proportions from tuna and research vessel sighting data, stratified by distance from previous sighting. Strata are based on euclidean distance rounded to the nearest degree (latitude and longitude are considered equivalent, see text for methods). Values are weighted averages of the species proportions in 5-degree geographic strata. Tuna vessel sightings include only those whose smeared perpendicular distances are less than 3 nautical miles.

Species	Distance (in degrees) from Previous Sighting 0	1	2	3+	Overall
TUNA VESSELS					
Identified					
Spotted dolphin	0.70	0.68	0.68	0.67	0.682
Spinner dolphin	0.17	0.19	0.19	0.19	0.182
Common dolphin	0.11	0.10	0.11	0.11	0.106
Striped dolphin	0.03	0.02	0.02	0.03	0.022
Fraser's dolphin	0.00	0.01	0.01	0.00	0.008
Total	1.0	1.0	1.0	1.0	1.0
Unidentified	0.14	0.13	0.16	0.18	0.153
# of Dolphins	4,660K	3,530K	1,160K	2,570K	11,900K
# of Schools	7206	5464	1959	4875	19504
RESEARCH VESSELS					
Identified					
Spotted dolphin	0.50	0.48	0.47	0.40	0.502
Spinner dolphin	0.21	0.21	0.23	0.16	0.226
Common dolphin	0.11	0.13	0.10	0.15	0.146
Striped dolphin	0.17	0.19	0.20	0.27	0.112
Fraser's dolphin	0.02	0.00	0.00	0.02	0.014
Total	1.0	1.0	1.0	1.0	1.0
Unidentified	0.09	0.16	0.18	0.09	0.069
# of Dolphins	82K	21K	12K	32K	148K
# of Schools	634	149	106	222	1111

Table 11. Dolphin species proportions from tuna vessel sighting data, stratified by whether the original sighting was made from helicopter or from ship. Values are weighted averages of the species proportions in 5-degree geographic strata. Included are sightings whose smeare perpendicular distances are less than or equal to 3 nautical miles.

	Sighting Platform		
Species	Helicopter	Ship	Overall
TUNA VESSELS			
Identified			
Spotted dolphin	0.79	0.68	0.682
Spinner dolphin	0.14	0.18	0.182
Common dolphin	0.06	0.11	0.107
Striped dolphin	0.01	0.04	0.021
Fraser's dolphin	0.00	0.01	0.008
Total	1.0	1.0	1.0
Unidentified	0.12	0.15	0.153
# of Dolphin	260K	11,800K	12,100K
# of Schools	325	19690	20015

Table 12. Species proportions for research vessel cruises within three geographic regions: inside the 1979 aerial survey area, outside that area and north of the equator, and outside that area and south of the equator. Values are given as both weighted and unweighted averages of the proportions within 5-degree strata, including only those sightings with a school size of 15 or greater. Standard errors from bootstrap are in parentheses.

INSIDE AERIAL REGION	Unweighted Average		Weighted Average	
Spotted	.39	(.042)	.49	(.041)
Spinner	.17	(.030)	.19	(.029)
Common	.27	(.043)	.19	(.039)
Striped	.16	(.030)	.11	(.025)
Fraser's	.01	(.003)	.01	(.003)
OUTSIDE AND NORTH OF EQUATOR	**Unweighted Average**		**Weighted Average**	
Spotted	.51	(.051)	.53	(.052)
Spinner	.27	(.030)	.26	(.030)
Common	.12	(.057)	.12	(.058)
Striped	.07	(.039)	.07	(.038)
Fraser's	.03	(.023)	.02	(.023)
OUTSIDE AND SOUTH OF EQUATOR	**Unweighted Average**		**Weighted Average**	
Spotted	.27	(.092)	.25	(.094)
Spinner	.31	(.128)	.30	(.131)
Common	.10	(.065)	.13	(.068)
Striped	.27	(.093)	.28	(.097)
Fraser's	.05	(.080)	.04	(.083)

Table 13. Species proportions for tuna vessel cruises within three geographic regions: inside the 1979 aerial survey area, outside that area and north of the equator, and outside that area and south of the equator. Values are given as both weighted and unweighted averages of the proportions within 5-degree strata, including only those sightings made within 3 NM perpendicular distance from the cruise track and with a school size of 15 or greater. Standard errors from bootstrap are in parentheses.

INSIDE AERIAL REGION	Unweighted Average		Weighted Average	
Spotted	.59	(.013)	.65	(.012)
Spinner	.16	(.010)	.17	(.008)
Common	.22	(.013)	.16	(.011)
Striped	.03	(.002)	.02	(.002)
Fraser's	.001	(.002)	.001	(.002)
OUTSIDE AND NORTH OF EQUATOR	**Unweighted Average**		**Weighted Average**	
Spotted	.70	(.022)	.71	(.020)
Spinner	.19	(.014)	.19	(.013)
Common	.08	(.021)	.07	(.020)
Striped	.02	(.004)	.02	(.004)
Fraser's	.01	(.003)	.01	(.003)
OUTSIDE AND SOUTH OF EQUATOR	**Unweighted Average**		**Weighted Average**	
Spotted	.58	(.032)	.56	(.031)
Spinner	.19	(.026)	.18	(.024)
Common	.15	(.029)	.17	(.027)
Striped	.08	(.012)	.08	(.012)
Fraser's	.002	(.001)	.002	(.001)

Table 14. Species proportions for research vessel cruises within three geographic regions: inside the 1979 aerial survey area, outside that area and north of the equator, and outside that area and south of the equator. Values are given as both weighted and unweighted averages of the proportions within 5-degree strata, including only those sightings with a school size of 15 or greater. All sightings are weighted by the inverse of log-school size. Standard errors from bootstrap are in parentheses.

INSIDE AERIAL REGION	Unweighted Average		Weighted Average	
Spotted	.38	(.039)	.48	(.037)
Spinner	.16	(.028)	.19	(.026)
Common	.26	(.039)	.18	(.034)
Striped	.19	(.029)	.14	(.025)
Fraser's	.01	(.003)	.01	(.003)
OUTSIDE AND NORTH OF EQUATOR	**Unweighted Average**		**Weighted Average**	
Spotted	.51	(.048)	.52	(.049)
Spinner	.26	(.029)	.25	(.028)
Common	.12	(.054)	.12	(.055)
Striped	.09	(.039)	.09	(.038)
Fraser's	.02	(.021)	.02	(.022)
OUTSIDE AND SOUTH OF EQUATOR	**Unweighted Average**		**Weighted Average**	
Spotted	.26	(.085)	.24	(.086)
Spinner	.30	(.116)	.29	(.118)
Common	.10	(.059)	.13	(.061)
Striped	.30	(.090)	.31	(.094)
Fraser's	.04	(.071)	.03	(.074)

Table 15. Species proportions for tuna vessel cruises within three geographic regions: inside the 1979 aerial survey area, outside that area and north of the equator, and outside that area and south of the equator. Values are given as both weighted and unweighted averages of the proportions within 5-degree strata, including only those sightings with a school size of 15 or greater. All sightings are weighted by the inverse of log-school size. Standard errors from bootstrap are in parentheses.

INSIDE AERIAL REGION	Unweighted Average		Weighted Average	
Spotted	.61	(.009)	.66	(.007)
Spinner	.15	(.006)	.17	(.005)
Common	.21	(.009)	.15	(.007)
Striped	.03	(.002)	.02	(.001)
Fraser's	.001	(.001)	.001	(.001)
OUTSIDE AND NORTH OF EQUATOR	**Unweighted Average**		**Weighted Average**	
Spotted	.70	(.011)	.71	(.010)
Spinner	.20	(.008)	.20	(.007)
Common	.08	(.011)	.06	(.010)
Striped	.01	(.003)	.01	(.002)
Fraser's	.01	(.002)	.01	(.002)
OUTSIDE AND SOUTH OF EQUATOR	**Unweighted Average**		**Weighted Average**	
Spotted	.63	(.024)	.62	(.023)
Spinner	.16	(.021)	.16	(.020)
Common	.12	(.018)	.12	(.017)
Striped	.08	(.010)	.08	(.010)
Fraser's	.01	(.001)	.01	(.001)

Table 16. Means and standard errors of species proportions for teams of observers on 1982 and 1983 research vessel cruises. Included are only those sightings for which all observers on a team were able to make estimates. Teams were made up of 3 observers making independent estimates of school size and species compositions, with teams A & C being composed of previous research vessel observers and teams B & D being composed of previous tuna vessel observers.

	1982		1983		
	Team A	Team B	Team C	Team D	MEAN
Spotted dolphins					
mean proportion	0.59	0.52	0.39	0.19	0.42
standard error	(0.028)	(0.010)	(0.032)	(0.008)	(0.020)
Spinner dolphins					
mean proportion	0.23	0.17	0.16	0.20	0.19
standard error	(0.025)	(0.006)	(0.013)	(0.055)	(0.025)
Common dolphins					
mean proportion	0.15	0.22	0.26	0.50	0.28
standard error	(0.002)	(0.008)	(0.005)	(0.038)	(0.013)
Striped dolphins					
mean proportion	0.03	0.10	0.19	0.11	0.11
standard error	(0.003)	(0.015)	(0.025)	(0.011)	(0.014)
Number of Sightings	34	52	66	78	

Table 17. Proportions of dolphin school of various species mixes stratified by the species mix in the preceding sighting.

	Preceding School						
	>90% Spotted	>90% Spinner	>90% Common	>90% Striped	>90% Spot+Spin	Other Mixes	Overall
TUNA VESSELS							
>90% Spotted	67.4%	39.7%	14.0%	43.3%	49.0%	43.8%	50.7%
>90% Spinner	5.7	22.9	2.0	5.6	9.4	9.4	6.9
>90% Common	4.9	6.7	75.5	16.0	3.1	13.5	19.0
>90% Striped	3.1	2.8	3.2	20.6	2.3	3.3	3.6
>90% Spot+Spin	15.8	23.9	2.7	11.2	32.5	17.7	16.4
Other Mixes	2.7	3.6	2.5	3.5	3.6	11.9	3.2
Sample size	7,458	992	2,814	520	2,367	480	14,668
RESEARCH VESSELS							
>90% Spotted	41.8%	20.5%	4.3%	26.1%	23.5%	31.6%	25.2%
>90% Spinner	10.7	28.2	1.1	2.0	7.4	5.3	7.0
>90% Common	5.7	2.6	71.7	13.1	1.5	10.5	19.4
>90% Striped	23.8	15.4	15.2	47.7	16.2	26.3	28.0
>90% Spot+Spin	14.8	23.1	0.0	6.5	47.1	21.1	14.8
Other Mixes	1.6	10.3	7.6	2.6	4.4	5.3	4.4
Sample size	122	39	92	153	68	19	500

Table 18. Summary of statistical tests comparing the frequency of sighting a given school type, contingent on the type of the previous school sighted. School types were tested pairwise within 5-degree squares. Fisher's exact test was used to test whether the probability of sighting a given school type is enhanced if the previous school was of the same type (1-tailed test). The table includes the number of species-pairs that were tested, the number of cases that showed a greater probability of sighting schools of one type if the previous school was of the same type, and the number of cases for which this enhanced probability was statistically significant.

School Types		Number of Pairs Tested	Number Showing Geographic Heterogeneity	Number Showing Significance ($p < 0.05$)
>90% Spotted	>90% Spinner	24	24	16
	>90% Common	22	22	18
	>90% Striped	15	13	10
	>90% Spot. + Spin.	39	37	17
>90% Spinner	>90% Common	9	9	9
	>90% Striped	1	1	1
	>90% Spot. + Spin.	18	15	5
>90% Common	>90% Striped	10	10	7
	>90% Spot. + Spin.	7	6	6
>90% Striped	>90% Spot. + Spin.	3	3	3